Identifying Catchment Areas near Selected Mountains in the Philippines using FlowViz

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ABSTRACT

This paper presents FlowViz, a software tool for modeling, simulation, and visualization of surface water flow. FlowViz was used in identifying possible catchment areas near selected mountains in the Philippines to locate places where flood might occur.

1. INTRODUCTION

Disaster management is the discipline of dealing with and avoiding risks and involves preparing for disaster before it occurs [10]. These disasters may be natural or human-made and can cause damage to property and human life. One such disaster is flood, which is an overflow or accumulation of an expanse of water that submerges land [11]. There are several factors that cause flood including excessive surface runoff due to storms and typhoons. Floods result to physical damage and casualties, contamination of water supplies, food shortage, and other devastating effects [11]. Although majority of floods are caused by natural factors and can thus be difficult to predict, planning ahead can be done, given relevant information, in order to minimize the damage they may cause.

Modeling, simulation, and visualization are essential computational tools that can be used to generate information needed for planning. These computational techniques accept data input and produce some output based on the values of the model parameters and simulation runs. These outputs can then be used for decision-making and planning. Models can be validated by comparing the results of the simulation with actual observations, if available.

This paper presents FlowViz, a software developed to model the surface water flow over a wide area based on digital elevation models. Being able to model the surface water flow will allow the identification of possible catchment areas where flood might occur in the future. The succeeding sections describe the data input and output, flow model, software architecture, experiments, and simulation results.

2193	2233	2245	2242	2228	2200
2254	2296	2316	2315	2289	2252
2312	2361	2389	2382	2343	2279
2338	2399	2445	2414	2363	2301
2336	2379	2406	2395	2351	2298
2307	2353	2364	2327	2296	2258

Figure 1: Example DEM raster (in meters).

Although there are existing applications similar to FlowViz, classified under Geographic Information System (GIS) [12] , most of them are commercial and will require extra cost to customize. In addition, due to the integrated architecture of these existing systems, they cannot handle large data sets for wide area simulations.

2. DATA INPUT AND OUTPUT

The primary input to FlowViz is the Digital Elevation Model (DEM). A DEM is a digital representation of ground surface topography or terrain [9]. DEMs are generated using remote sensing in order to cover larger geographical area, although traditional surveying can still be used. They are described using a grid or matrix with values in each cell representing elevation data. DEMs can vary in resolution. The resolution pertains to the total area covered by the elevation value. Figure 1 shows an example of a DEM in the ESRI ASCII Grid Format [6].

Another input used by FlowViz is the precipitation data. Precipitation data is described by the Probability of Precipitation (POP). It is a formal measure of the likelihood of precipitation used in weather forecasting [8]. In FlowViz, precipitation data is represented also as a grid with the amount of precipitation specified in each cell. There is a one-to-one mapping between the DEM grid and the precipitation grid, that is, each elevation cell has a corresponding precipitation cell. Depending on the given POP, a precipitation cell may

1	1	0	1	1	1
1	1	1	1	1	1
1	0	1	1	1	1
0	1	0	1	0	1
1	1	1	1	1	1
0	0	0	1	1	0

Figure 2: Precipitation raster.

have zero(0) or one(1) amount of precipitation. Figure 2 illustrates a precipitation grid with a POP of 75% for the given DEM in Figure 1.

The main output of FlowViz are the latitude and longitude coordinates of possible catchment areas. In addition, a 3D visualization of the DEM, with catchment areas marked, are also provided.

3. FLOW MODEL

The flow model describes the speed, direction, and amount of flow over time. Normally it is modelled by solving a set of non-linear partial differential equations such as the Navier-Stokes equation [13]. Together with other equations such as conservation of mass, Navier-Stokes equation can more or less accurately model the flow. Shallow water equations can also be used in cases when the horizontal length scale is greater than vertical length scale. A simpler equation is used for Newtonian fluids, such as water, which flows continuously regardless of the external forces [7].

Although models based on differential equations may provide more accurate behavior of the flow, they are computationally expensive resulting to longer simulation times, especially for wide area simulations. Also, values of the parameters in the equations may not be available thus estimates must be made which can affect the accuracy of the model.

FlowViz uses the Deterministic Eight-node (D8) [5] flow model which is a simple flow model that describes the direction of the flow from one cell to a neighboring cell by computing the aspect or slope. The derivation of the flow direction can further be simplified by finding the neighboring cell with the lowest elevation and marking it as the direction of the flow. In D8, the flow from one cell will be towards a single direction only, the neighbor cell with the lowest elevation. The flow map raster in Figure 3 illustrates flow directions from one cell to another derived using D8 given the DEM in Figure 1. The values in the raster represent the direction based on the convention NW=0, N=1, NE=2, W=3, CENTER=4, E=5, SW=6, S=7, SE=8.

After a flow map has been generated, it can be used to identify catchment areas as shown in Figure 4. The next section describes how this is done.

0	0	0	0	0	0
0	0	0	2	2	0
0	0	0	2	2	0
0	0	0	2	2	0
0	6	8	8	8	0
0	0	0	0	0	0

Figure 3: Flow map raster derived using D8.

2	1	0	1	1	1
1	2	1	1	1	1
1	0	0	0	1	1
0	1	0	0	0	1
2	1	1	1	1	1
0	0	0	1	1	0

Figure 4: Catchment areas are cells with values greater than or equal to 2.

4. SOFTWARE ARCHITECTURE

Two common approaches of representing data in Geographic Information Systems (GIS) software are raster and vector [12]. Raster data is represented by grids and is generally regarded as an image. The basic unit of raster data is the cell, or pixel in images, which contains a single value. Vector formats on the other hand describes data in geometric terms such as points, lines, and polygons. FlowViz uses raster as its primary data structure. Rasters are easy to manipulate and can be directly represented in programming languages as two-dimensional arrays. Thus, the DEM and precipitation inputs in FlowViz, together with other structures are internally represented as raster layers. An experiment in FlowViz is described by a project that contains a set of layers.

The handling of DEM input uses the Geospatial Data Abstraction Library (GDAL) [2] which supports different types of raster data formats, including images.

The algorithm used in the simulation is straightforward. First, the elevation data from the DEM is loaded using GDAL. The data is then converted to the internal representation of a layer in FlowViz. The second step is to derive the flow map layer using the D8 algorithm. Then precipitation data is generated as another layer by specifying a probability of precipitation over an area (or a cell in the DEM). The catchment layer is then created which specifies the current water level on an area. The initial amount on each cell in the catchment layer is initially set to the rainfall amount. A trace of the flow is then performed for each cell for a given number of iterations. The algorithm for identifying the catchments is outlined below.

```
(1) Load ELEVATION layer
(2) Generate FLOWMAP layer
(3) Generate RAINFALL layer given POP
(4) Create CATCHMENT layer
(5) Initially set CATCHMENT layer be
    equal to RAINFALL layer
(6) Set CURRENT be equal to a randomly selected
    unupdated cell from the set of all cells in
    ELEVATION
(7) Trace the flow from CURRENT using FLOWMAP
    layer for MAXSTEPS iterations, updating the
    water level in the cells in CATCHMENT layer
    along the flow path
(8) Mark CURRENT as updated
(9) Go to (6) until all the cells from ELEVATION
    have been updated
```

After the algorithm has finished, the values in each cell in the catchment layer will contain the final water level over the course of the simulation. The cells in the catchment layer will be sorted in decreasing order based on the water level. A given threshold can be specified to limit the number of possible catchment areas returned. Note that in the algorithm above, ELEVATION, FLOWMAP, RAINFALL, and CATCHMENT have the same dimensions.

FlowViz was implemented in the C programming language and OpenGL was used for the 3D visualization. The source code is available online [1].

Table 1: Mountain areas studied

Mountain	Latitude	Longitude
Mt. Makiling	14.13054	121.19048
Mt. Banahaw	14.06394	121.42523
Mt. Isarog	13.66670	123.38300
Mt. Mayon	13.25520	123.68600

5. EXPERIMENTS

Using FlowViz, experiments were performed to determine the possible catchment areas near selected mountains in the Philippines, particularly those in the southern part of Luzon. Catchments are areas most likely water will accumulate over time given the amount of precipitation and elevation data. It should be noted, however, that more complex models will include infiltration, evaporation, surface roughness, and other variables that will make the model more accurate and realistic. In this study however, the inputs were limited to only the precipitation and elevation data because it is difficult to obtain the previously mentioned information. It is however easy to include them later in FlowViz because of its layered architecture.

For the DEM input, the data set publicly available online from USGS Shuttle Radar Topography Mission [4] was used. The resolution of this data is 90m per cell. The data set for the entire Philippines is composed of six tiles. These tiles were downloaded in ESRI ASCII Grid format. The experiments specifically used the data from the middle tile, named srtm_61_10.asc, in the original data set.

Precipitation input was generated by specifying a probability of precipitation over the selected area. Table 1 shows the location of the subject mountains.

The simulations were run three times over a 260x260 cell area centered on the subject mountain given a POP of 75%. The coordinates of the identified catchment areas were used as input to Google Maps [3] to approximate the name of the area.

The hardware used in the experiment is a 1.5 Ghz IBM R50e Thinkpad with 1GB of RAM and 40GB disk space running Ubuntu 9.04 operating system.

6. RESULTS AND DISCUSSION

Tables 2-13 show the catchment areas identified near the mountains of Mt. Makiling, Mt. Banahaw, Mt. Isarog, and Mt. Mayon. Figures 5-8 show the 3D wireframe view of the study areas. The yellow dots represent the pixels that are considered catchment areas. Only the top five catchment areas were noted and presented in the tables. For areas near Mt. Makiling and Mt. Banahaw, San Pablo City and Victoria Laguna seem to be present in the results because these areas are between the two mountains. In the case of Mt. Isarog, areas near the foot of the mountain is where majority of the catchments are located. On the other hand, catchments near Mt. Mayon are near the sea. Figure 9 illustrates how the name of the catchment area is approximated using Google Maps.

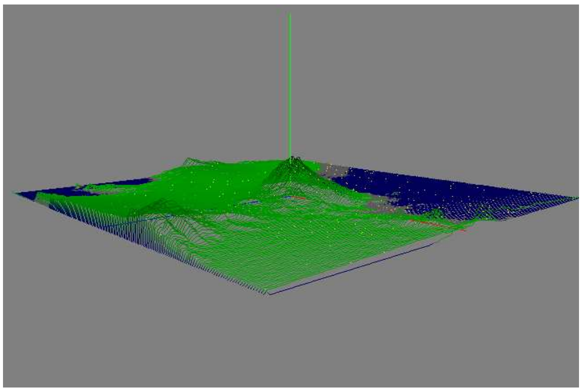

Figure 5: Mt. Makiling.

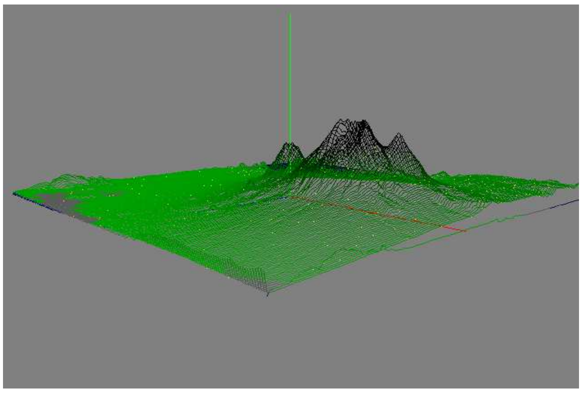

Figure 6: Mt. Banahaw.

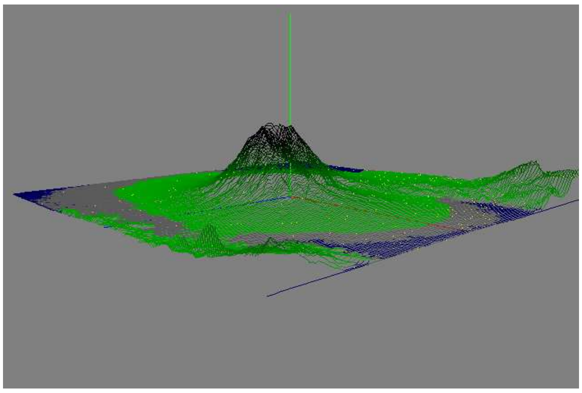

Figure 7: Mt. Isarog.

Table 2: First Run for Mt. Makiling with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
14.228308	121.329468	Victoria Road, Pila
14.219978	121.097893	CA Yulo Avenue Calamba
14.214148	121.062904	Nuvali, near AUP
14.151672	121.147041	near Lyceum
14.069204	121.302811	AH26, San Pablo

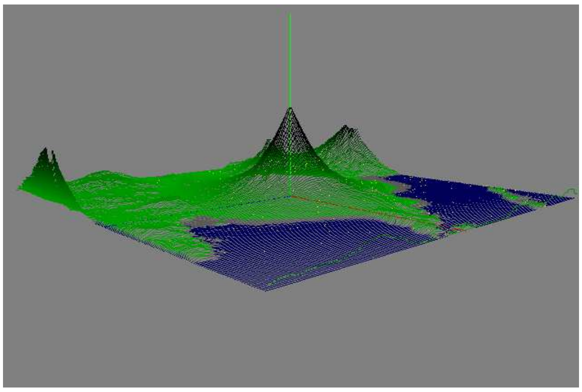

Figure 8: Mt. Mayon.

Table 3: Second Run for Mt. Makiling with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
14.197487	121.142876	Real Road Calamba
14.237471	121.089561	Sta. Elena Golf Course
14.210815	121.326134	Brgy. San Felix Victoria
14.164167	121.295319	Brgy. Dila, Bay-Calauan
14.194988	121.130379	Calamba Industrial Park

Table 4: Third Run for Mt. Makiling with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
14.212481	121.204521	Laguna Lake
14.005064	121.337799	AH26, San Pablo
14.276622	121.073738	Laguna Bel Air
14.166666	121.318642	Brgy. Dayap, Bay-Calauan
14.084199	121.182861	AH26, Sto. Tomas Batangas

Table 5: First Run for Mt. Banahaw with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
14.189990	121.339462	Rd, Victoria Laguna
14.096694	121.321136	Calauan-San Pablo Hway
14.044215	121.346130	San Pablo City
14.190823	121.326965	Brgy. Masapang Rd., Victoria
14.080034	121.356125	near Bunot Lake, San Pablo

Table 6: Second Run for Mt. Banahaw with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
14.211648	121.446091	Magdalena, Quezon
14.126682	121.347794	near Mojicap Lake
14.185825	121.512726	Brgy. San Diego Luisiana
14.060875	121.296982	near AH26, San Pablo
14.058376	121.488571	Mt. Banahaw

Table 7: Third Run for Mt. Banahaw with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
14.202485	121.458580	Brgy. Banilad, Magdalena
14.102525	121.341965	near Palakpakin Lake SPC
14.167500	121.501900	Brgy. San Luis, Luisiana
14.059209	121.315308	near AH26, San Pablo
13.980907	121.501900	near Mt. Bayabobo

Table 8: First Run for Mt. Isarog with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
13.577735	123.365318	foot of Mt. Isarog
13.706850	123.404472	foot of Mt. Isarog
13.556077	123.511925	Sangay Cam. Sur
13.747667	123.515259	Goa Road Cam. Sur
13.632713	123.487770	Tigaon Cam. Sur

Table 9: Second Run for Mt. Isarog with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
13.633546	123.303680	Cararayan, San Isidro Rd
13.586898	123.295349	near Naga Airport
13.659369	123.432793	Mt. Isarog
13.734339	123.465279	near Goa, Cam. Sur
13.801812	123.396973	Tinambac, Cam. Sur

Table 10: Third Run for Mt. Isarog with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
13.746834	123.351158	near Tinambac, Cam. Sur
13.801812	123.439453	near Lagonoy, Cam. Sur
13.805144	123.392807	near Tinambac, Cam. Sur
13.656870	123.269524	near Pacol-Carolina Road
13.794315	123.430298	near Lagonoy Cam. Sur

Table 11: First Run for Mt. Mayon with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
13.223710	123.771820	Bigaa shoreline
13.401139	123.679359	foot of Mt. Malinao
13.362822	123.831802	Bacacay
13.402805	123.700188	Ntl Hway, Malinao
13.276189	123.794312	near Pili Bacacay

Table 12: Second Run for Mt. Mayon with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
13.232040	123.812637	near Bacacay shoreline
13.345328	123.545250	foot of Mt. Masaraga
13.361155	123.561073	foot of Mt. Masaraga
13.322004	123.743500	Panarayon Beach
13.386978	123.814308	San Miguel Bay

Table 13: Third Run for Mt. Mayon with dimensions 260x260 and POP of 75 percent for 10 iterations

Latitude	Longitude	Approximate Area
13.215380	123.766823	Bigaa Shoreline
13.138744	123.686028	AH26, Legazpi City
13.337831	123.780151	Sea
13.381980	123.705185	Ntl Hway, Malinao
13.216213	123.577736	AH26, Guinobatan

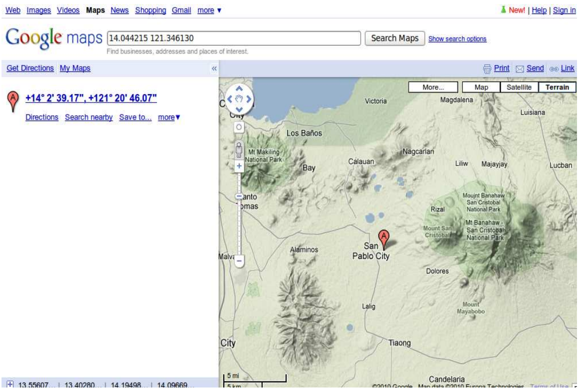

Figure 9: Google Maps showing an identified catchment area near Mt. Banahaw.

7. CONCLUSION

This paper presented FlowViz, a software tool for modeling surface water flow based on digital elevation models. Using the D8 flow routing algorithm, a flow map is derived and given precipitation data, possible catchment areas can be identified by simulating the water flow and determining the water level in the areas. FlowViz was used to identify possible catchment areas near selected mountains in the Philippines.

8. ACKNOWLEDGMENTS

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